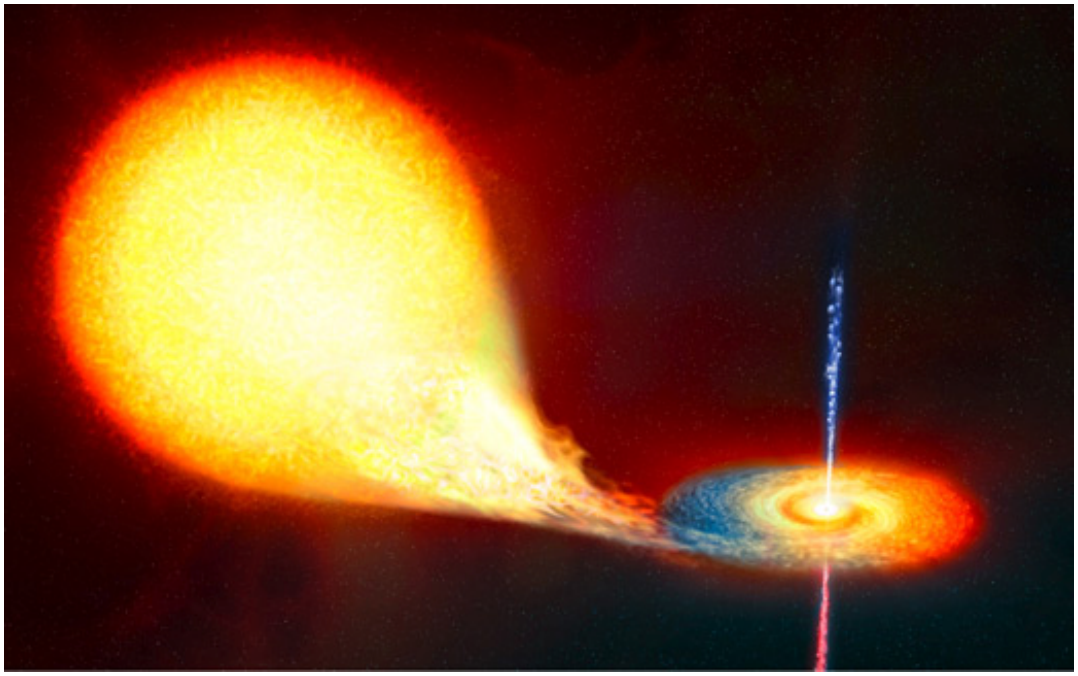
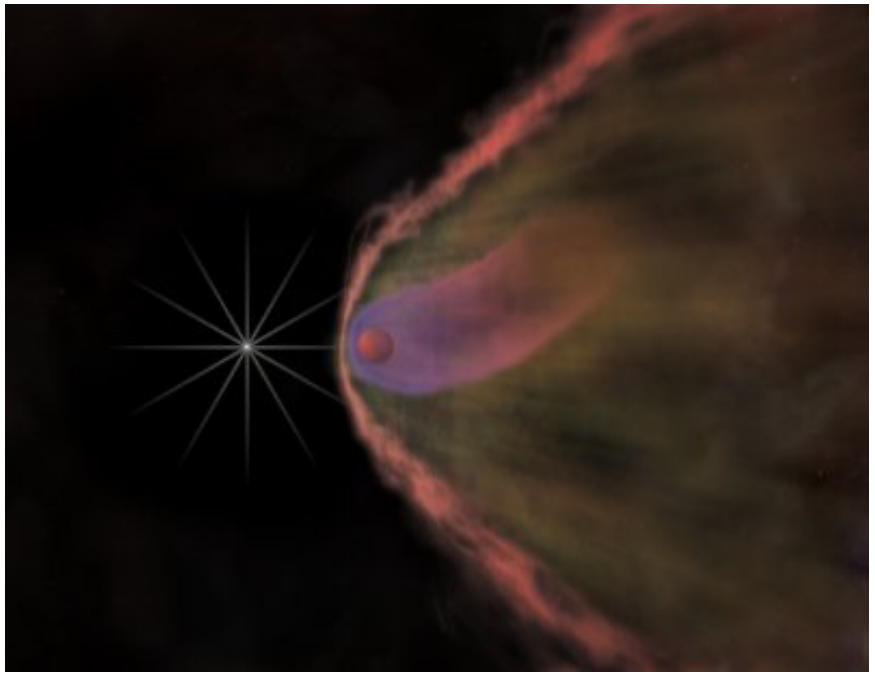
# New Binaries Among *Fermi* Unassociated Sources

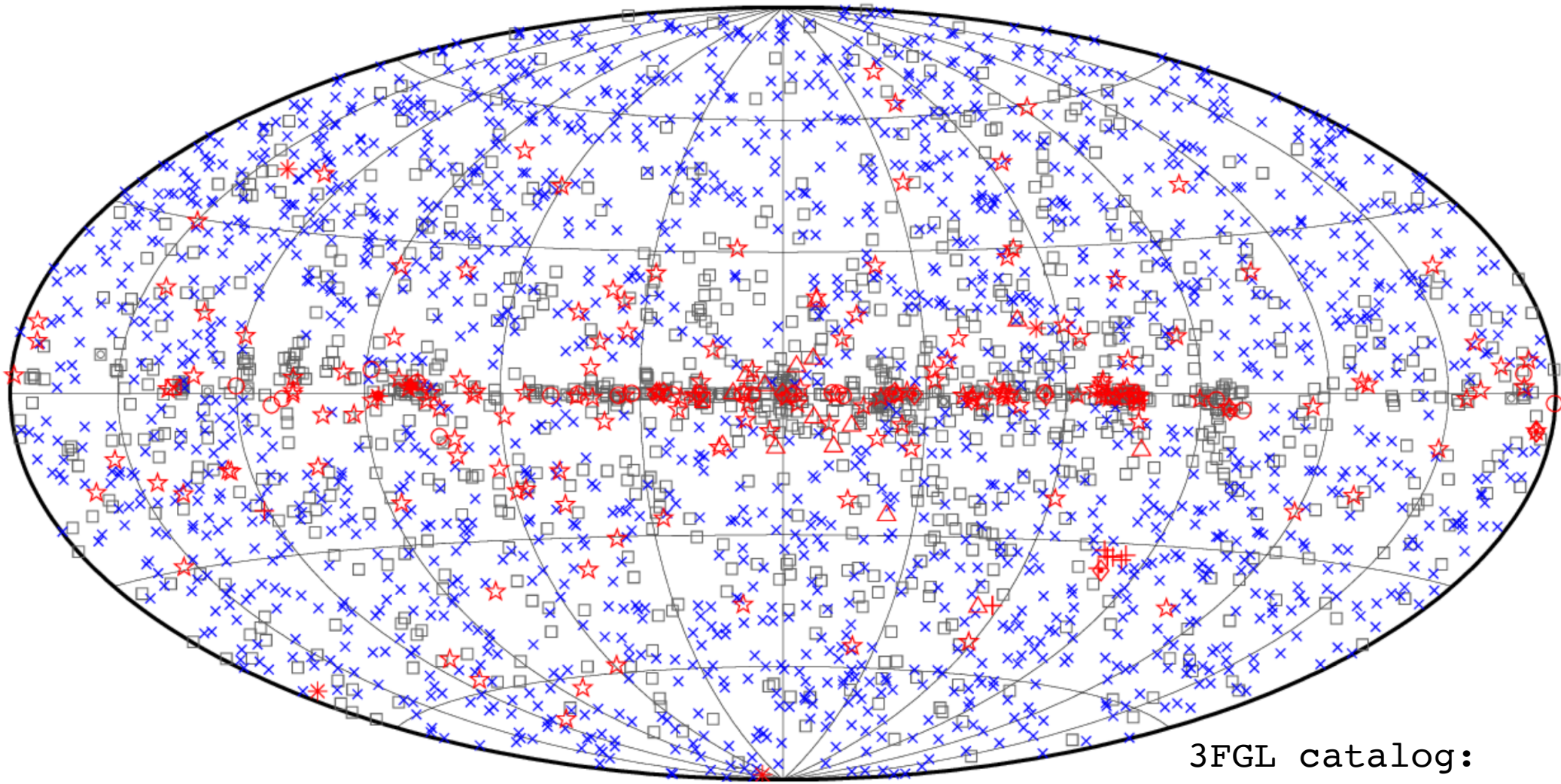




Laura Chomiuk (Michigan State)

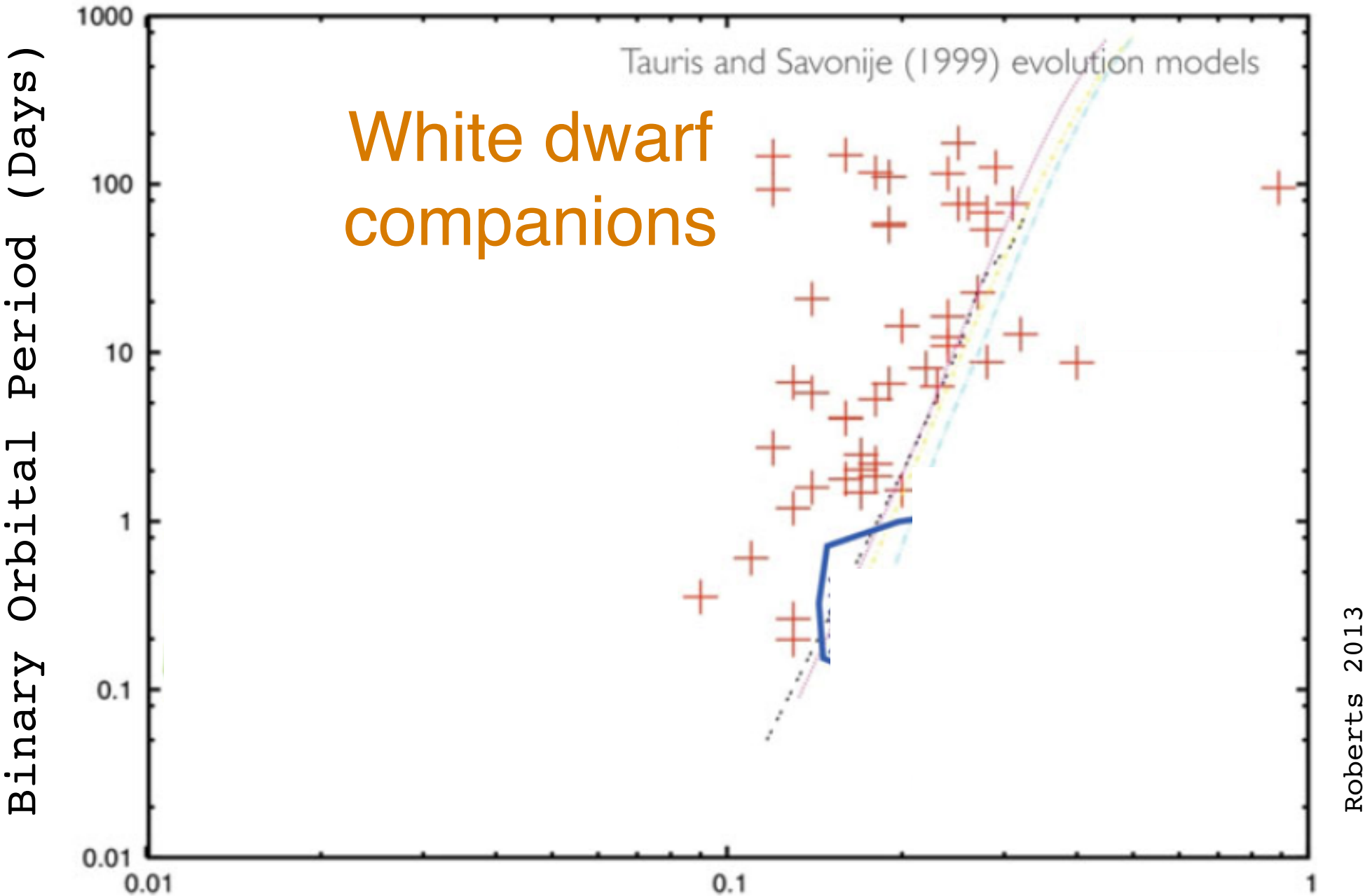
Jay Strader, **Sam Swihart**, **Ray Li** (Michigan State), Teddy Cheung (NRL), Dave Sand (Texas Tech), James Miller-Jones (Curtin), Craig Heinke (Alberta)

# Large swaths of discovery space remain— including γ-ray emitting binary stars

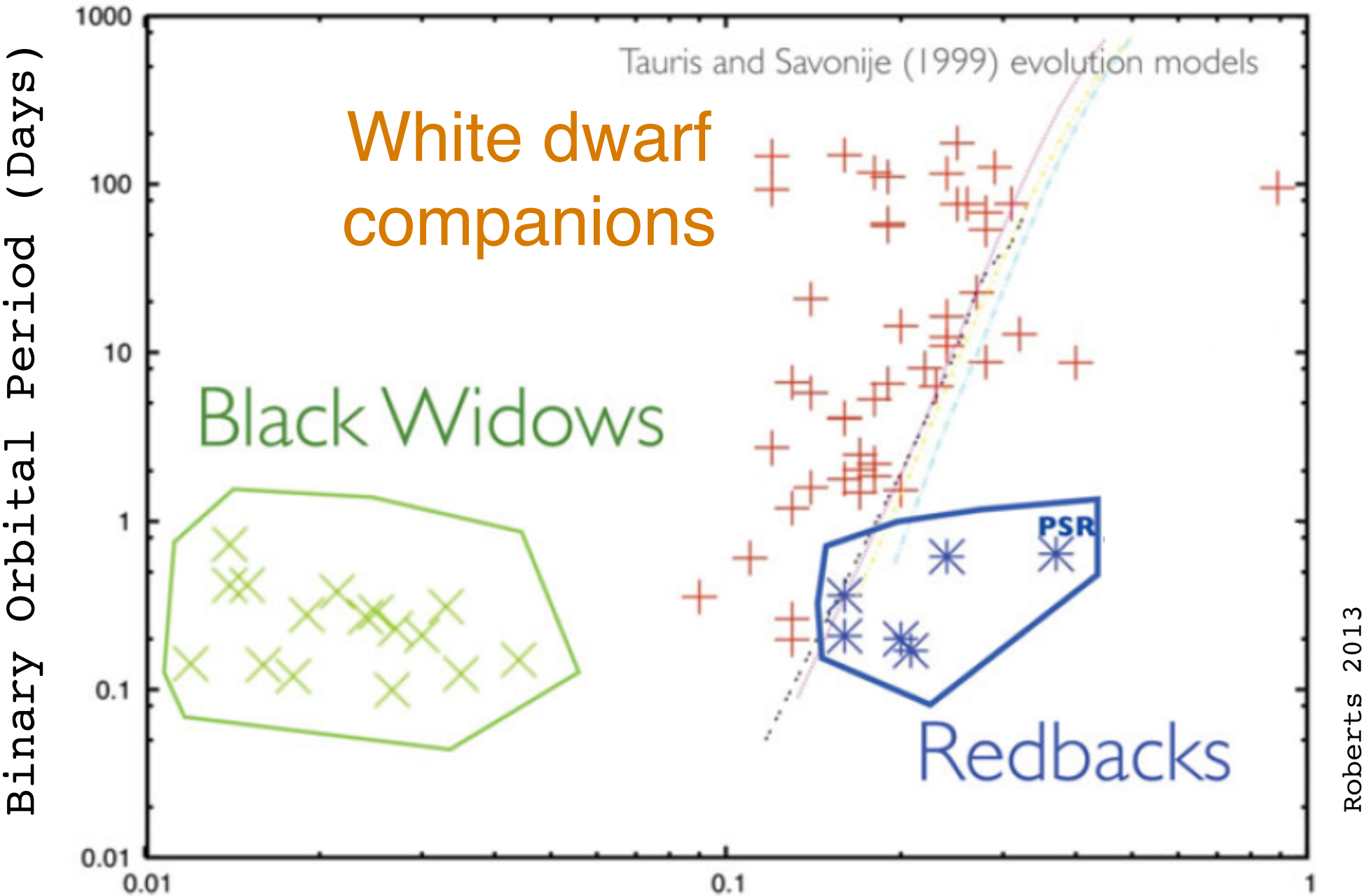


3FGL catalog:
nearly 1000 sources
“unassociated”

# *Fermi* expands MSP parameter space

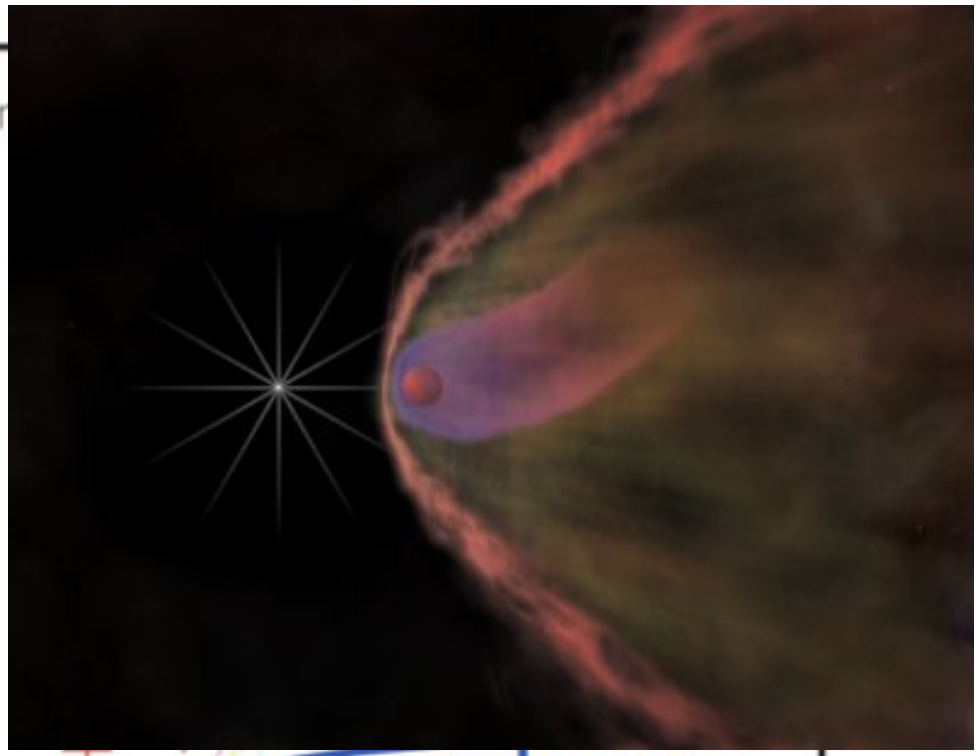


# *Fermi* expands MSP parameter space




Roberts 2013

# *Fermi* expands MSP parameter space



Black Widows

PSR J2129-0429

Redbacks

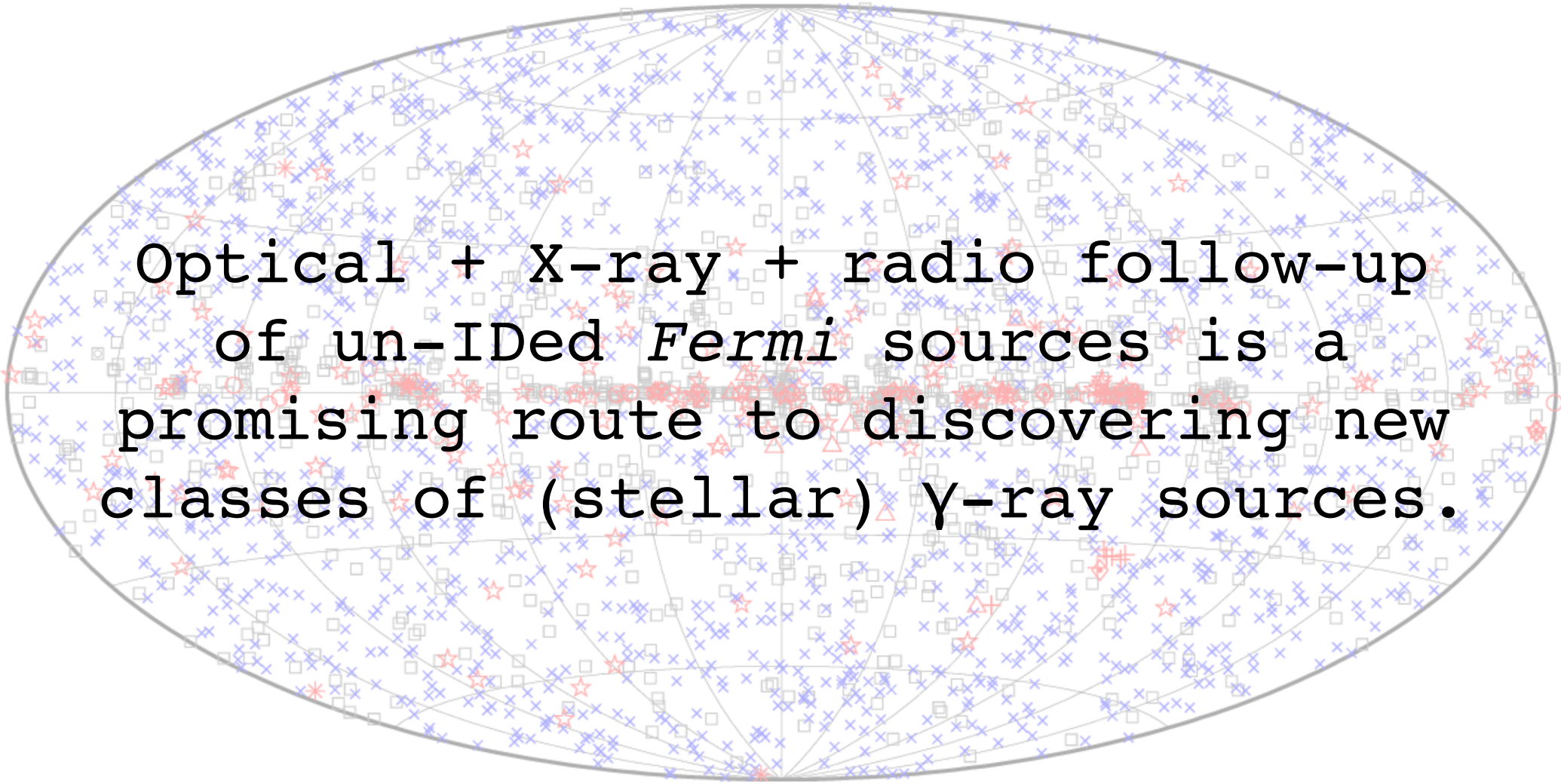
Roberts 2013

Binary Orbital Period (Days)

1000
100
10
1
0.1
0.01

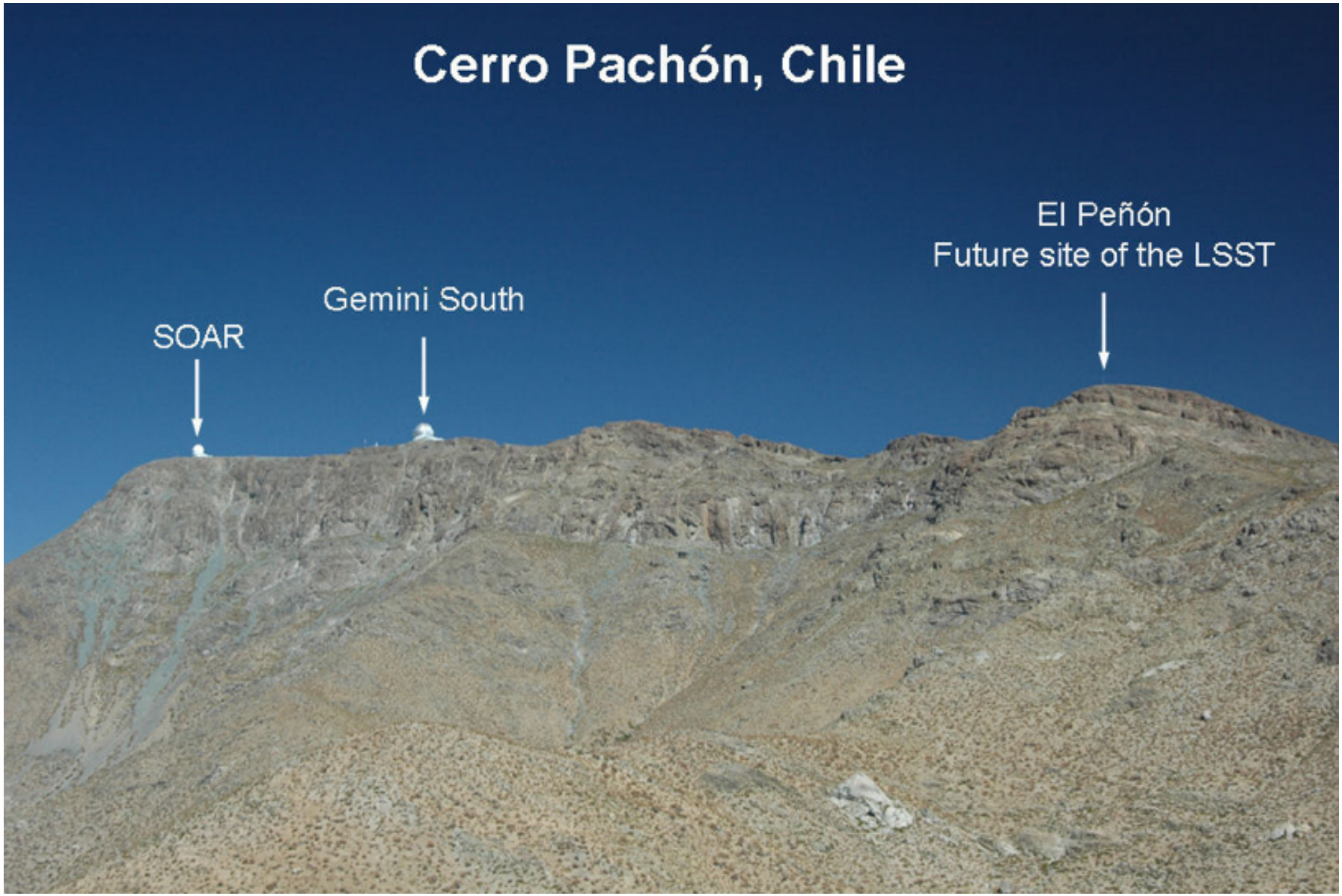
0.01
0.1
1

Minimum Companion Mass ($M_\odot$)



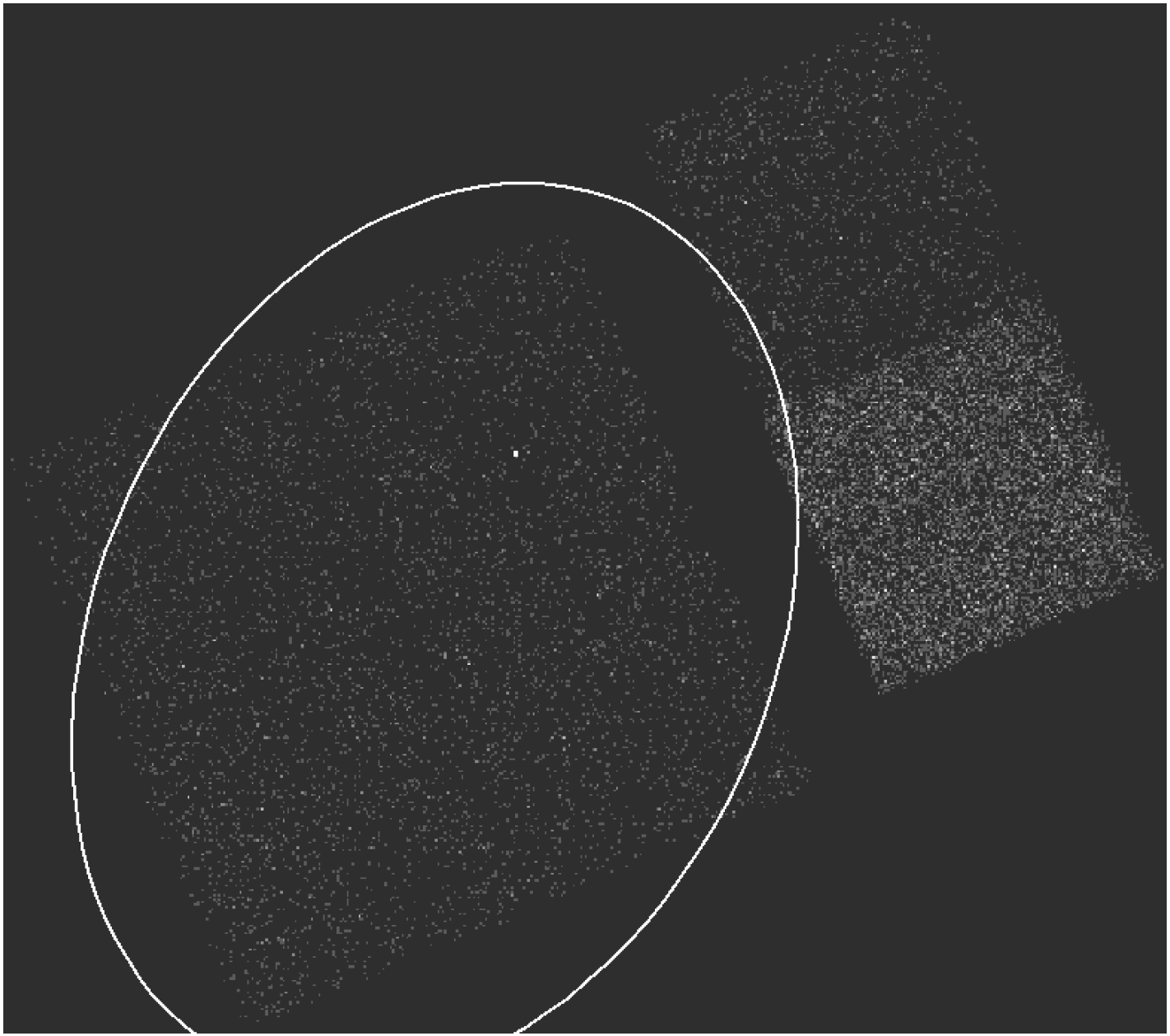
Optical + X-ray + radio follow-up of un-IDed *Fermi* sources is a promising route to discovering new classes of (stellar) γ-ray sources.

# 4.1m SOAR telescope



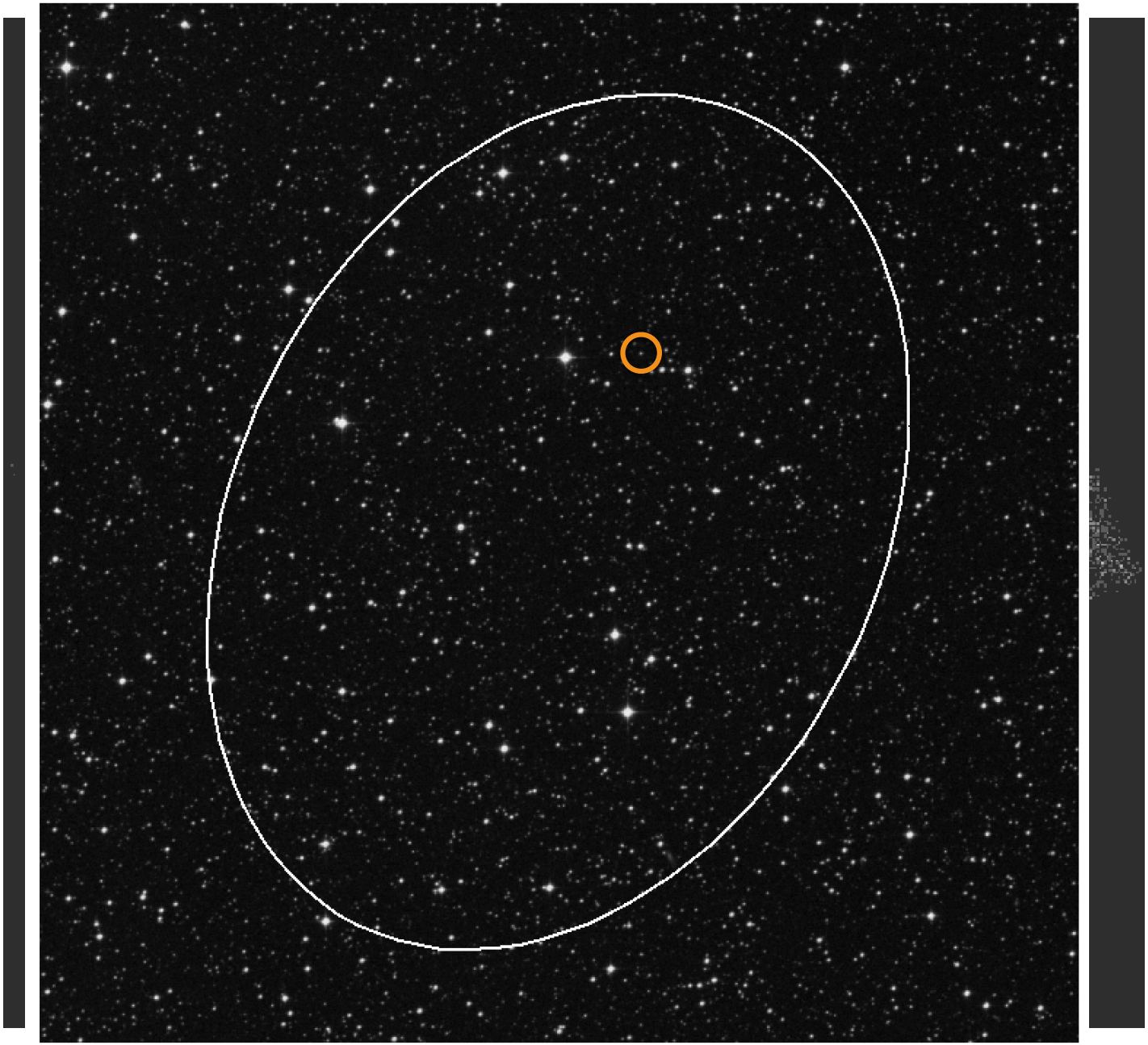

MSU + NOAO + Brazil + UNC

# 1FGL J1417.7-4407



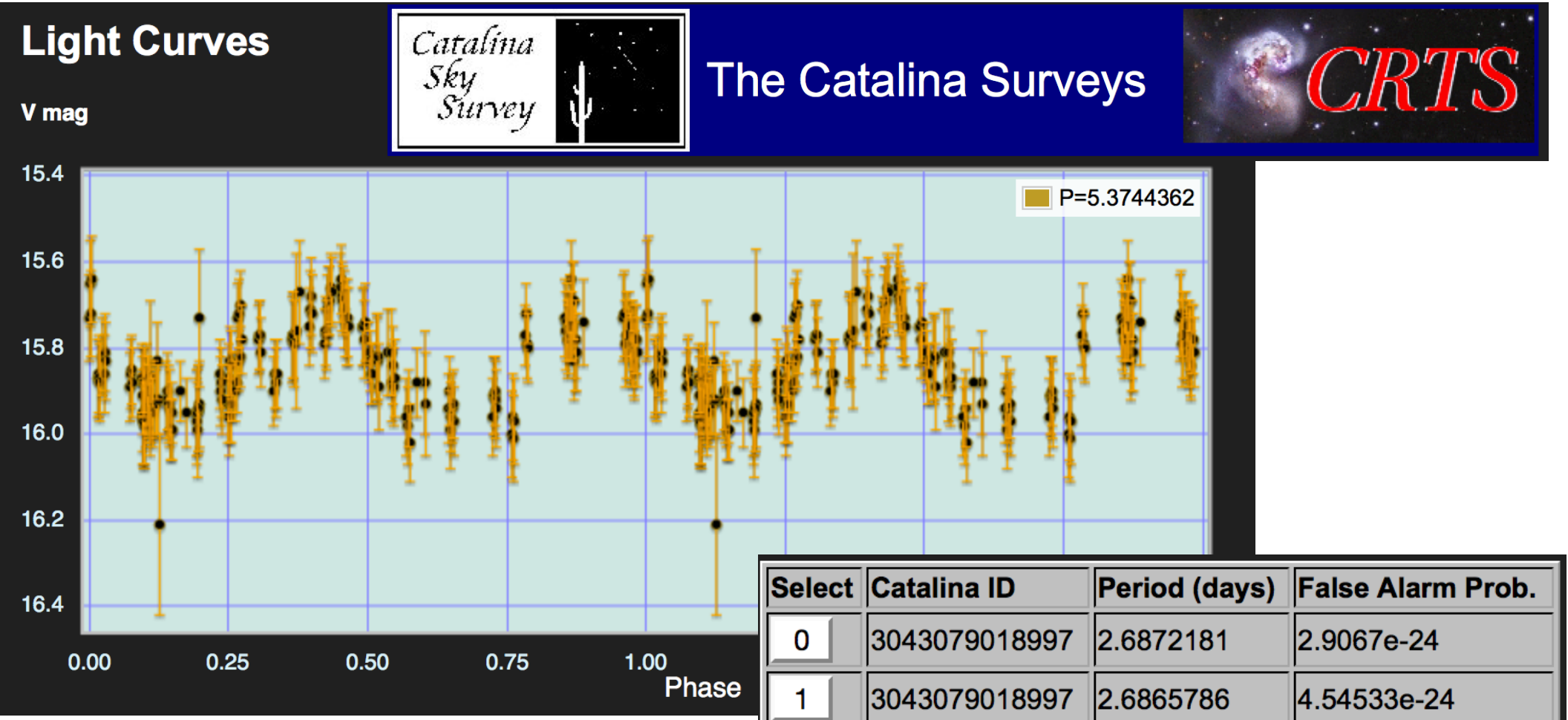
*Chandra* data
+ 1FGL error
circle

# 1FGL J1417.7-4407



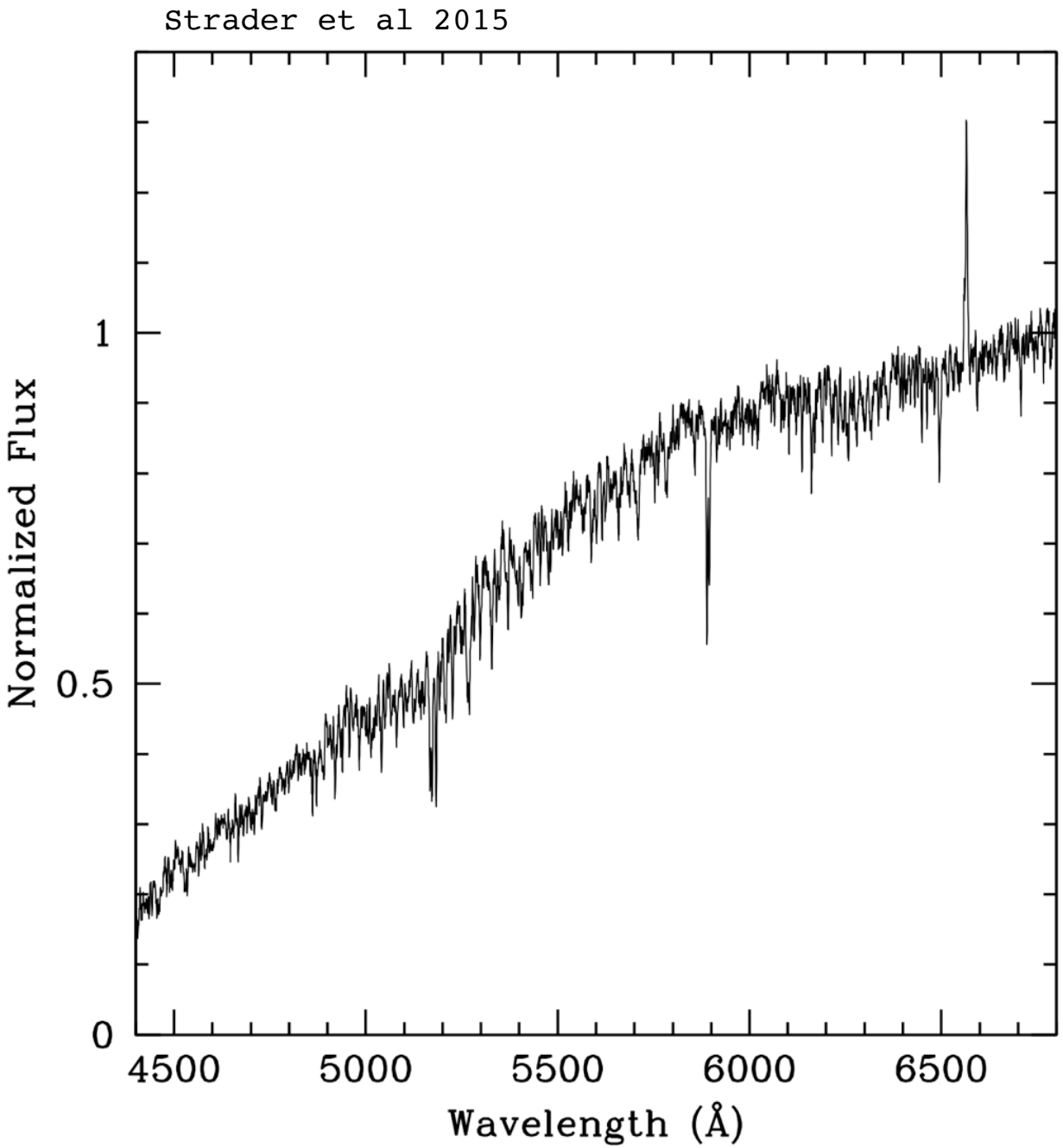
DSS image + *Chandra* position + 1FGL error circle

# Optical counterpart to 1FGL J1417?
# Looks periodic!




| Select | Catalina ID | Period (days) | False Alarm Prob. |
|---|---|---|---|
| 0 | 3043079018997 | 2.6872181 | 2.9067e-24 |
| 1 | 3043079018997 | 2.6865786 | 4.54533e-24 |
| 2 | 3043079018997 | 1.5857569 | 1.15099e-18 |
| 3 | 3043079018997 | 0.7272905 | 2.46113e-18 |
| 4 | 3043079018997 | 0.6132995 | 6.73207e-18 |
| 5 | 3043079018997 | 5.3744362 | 2.9067e-24 |

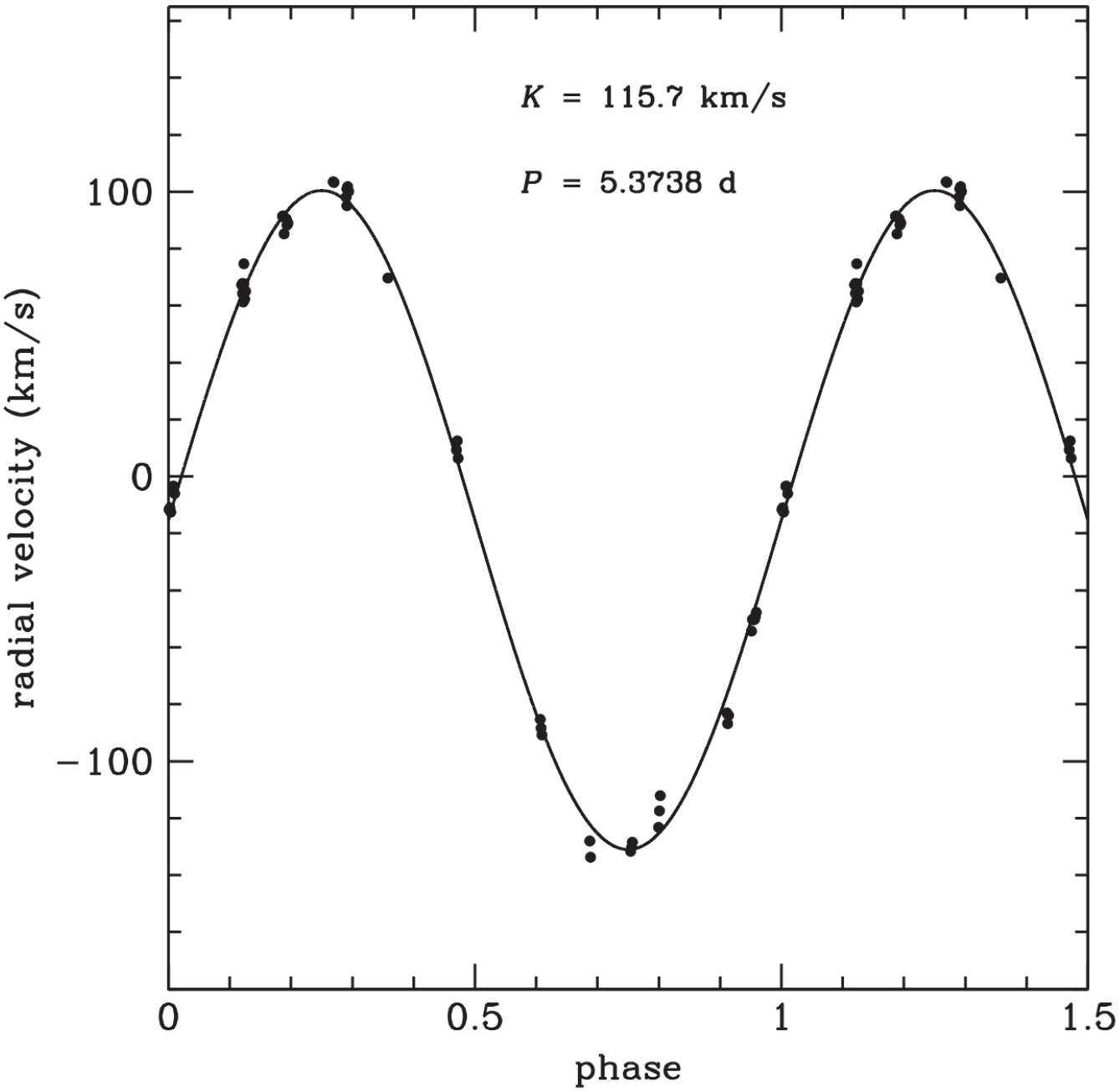
# Optical follow-up of J1417




Optical spectrum is a late G star

Almost always shows H-alpha in emission

# Optical follow-up of J1417

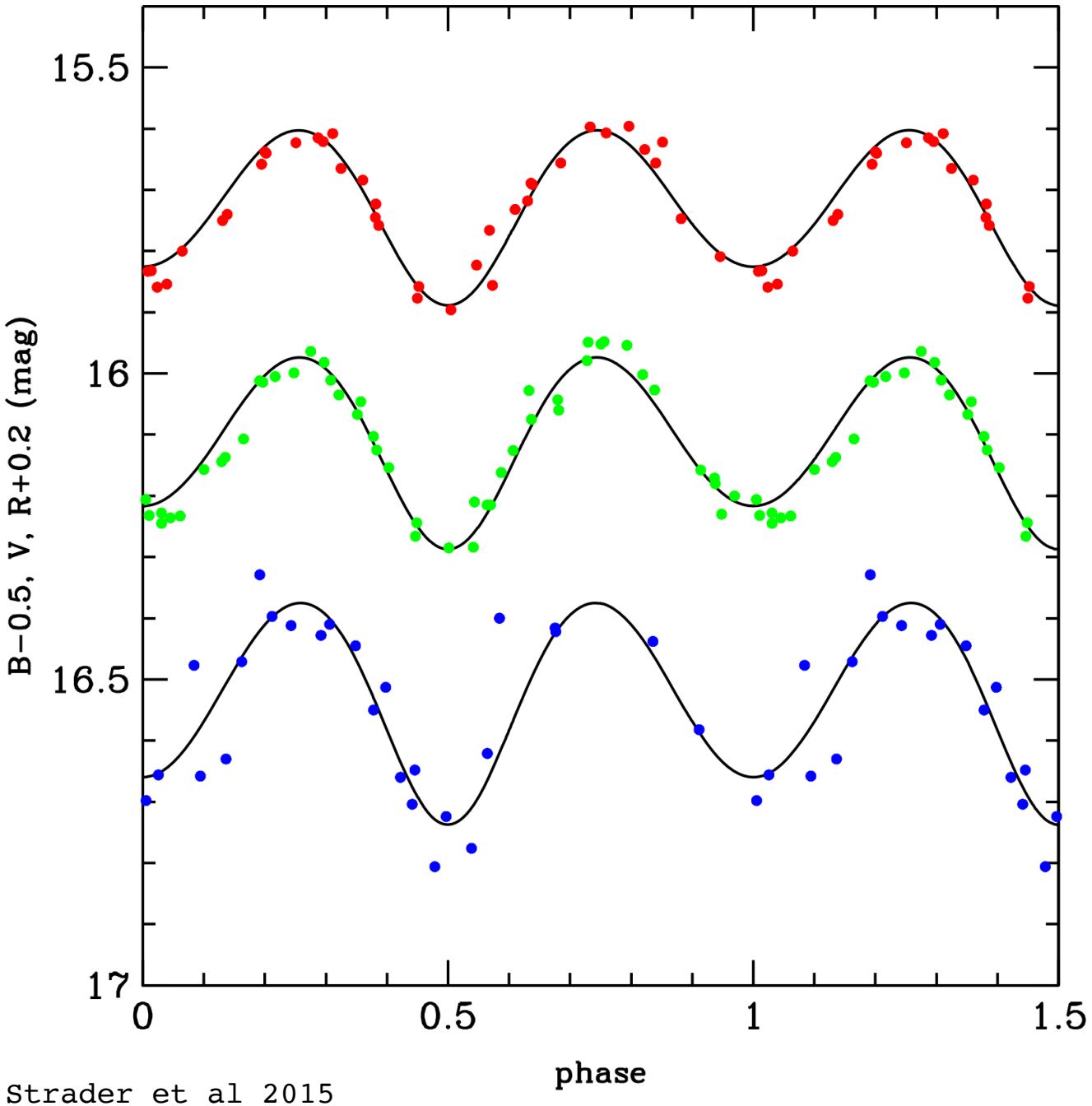



Strader et al 2015

Radial velocities from photospheric absorption lines trace the orbit of the secondary

K = 116 km/s
P = 5.374 days

# Optical follow-up of J1417



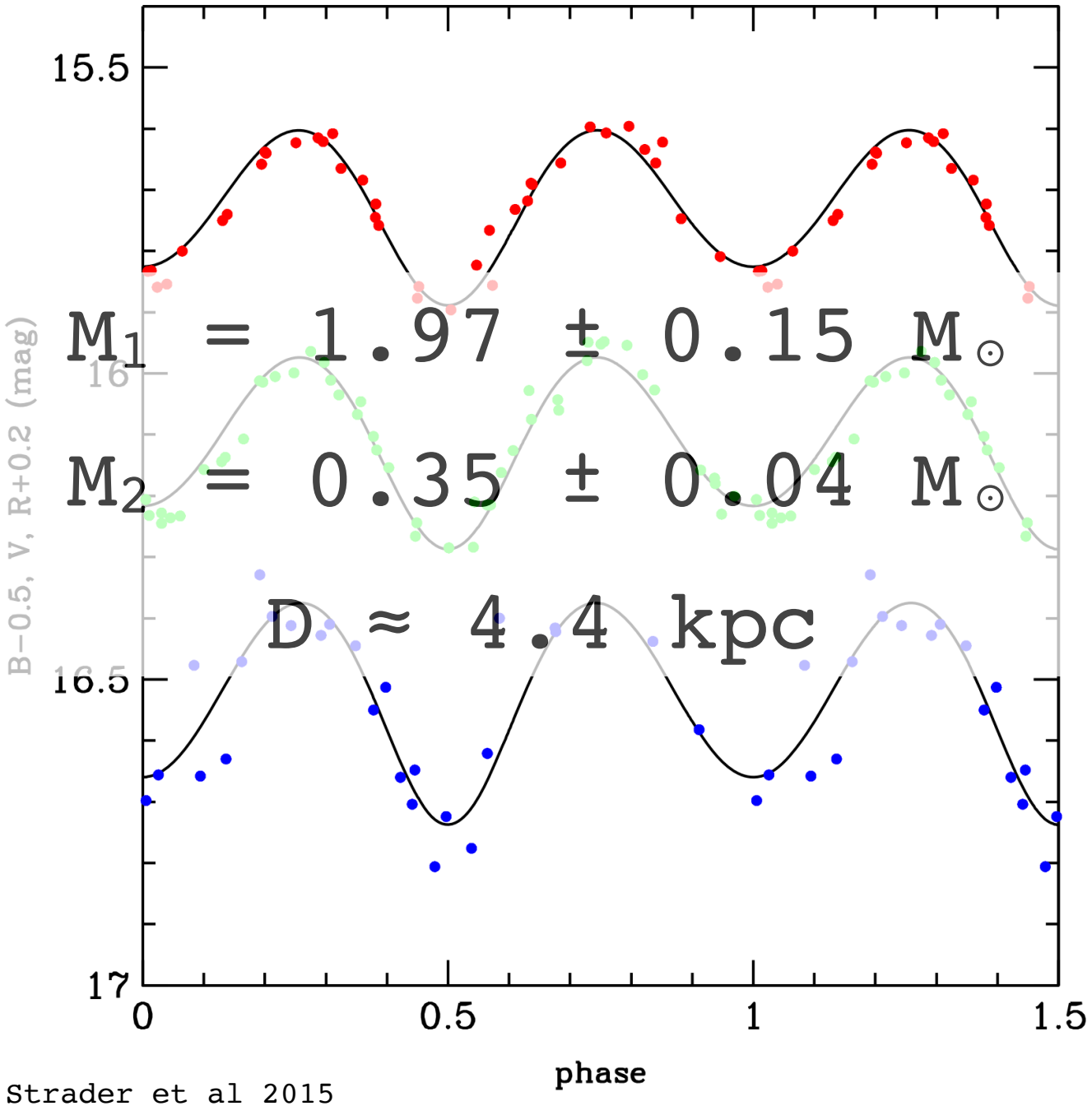

Strader et al 2015

Radial velocities from photospheric absorption lines trace the orbit of the secondary

+

Multi-color photometry constrains inclination

# Optical follow-up of J1417



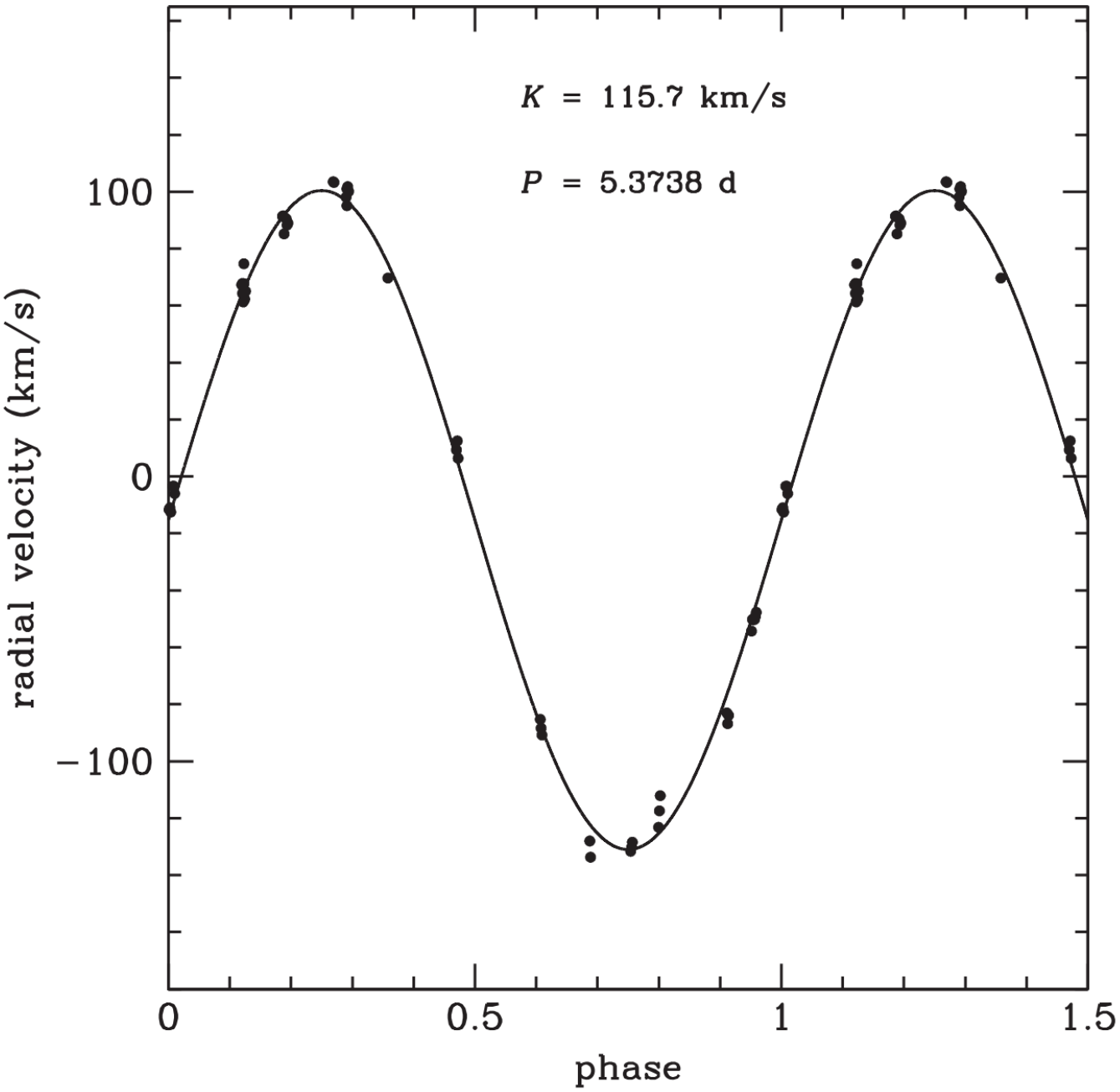

Strader et al 2015

Radial velocities from photospheric absorption lines trace the orbit of the secondary

+

Multi-color photometry constrains inclination

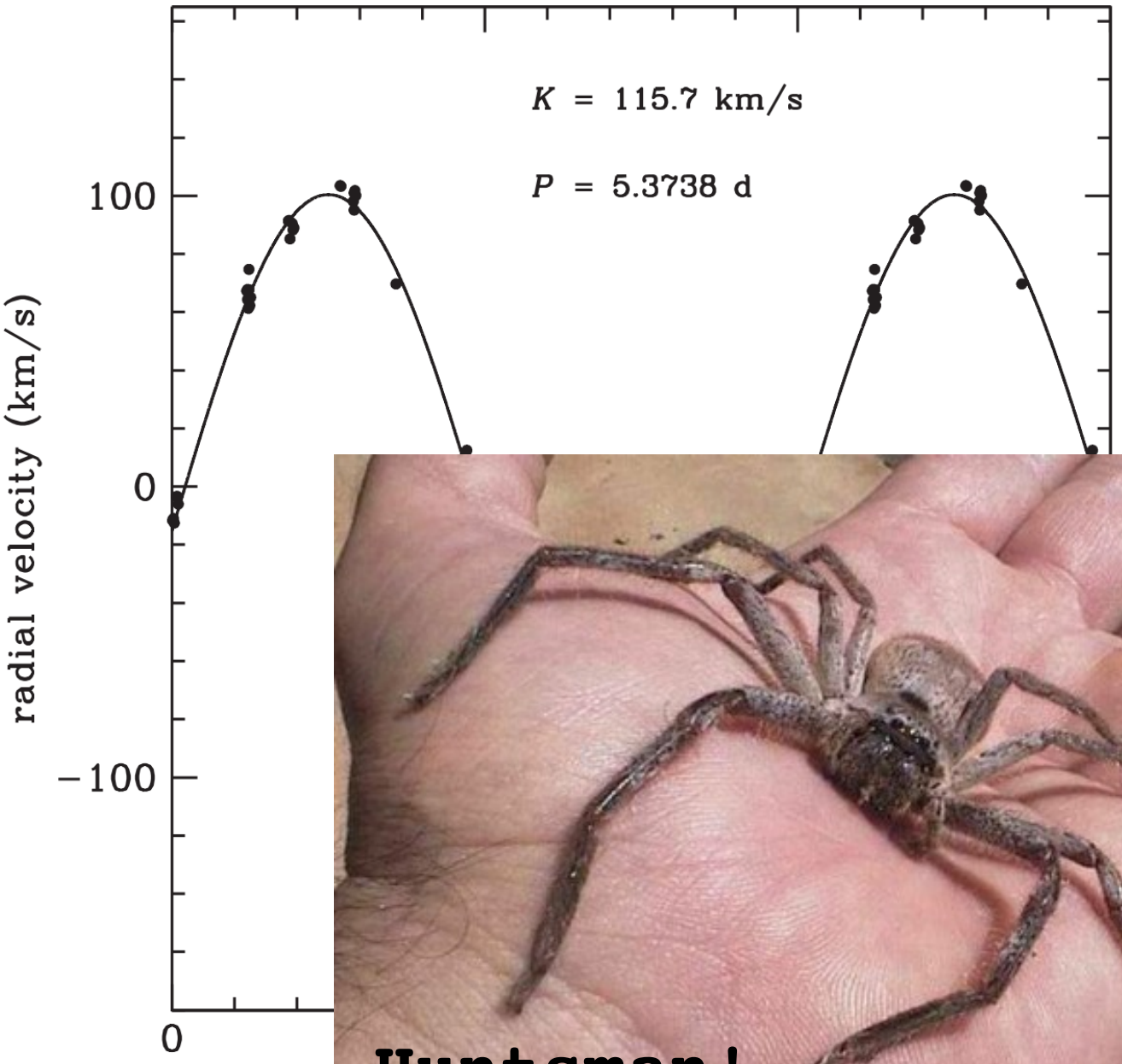
# Optical follow-up of J1417




Strader et al 2015

Long Period (5.4 days)➜ **Red giant** secondary!

# Optical follow-up of J1417

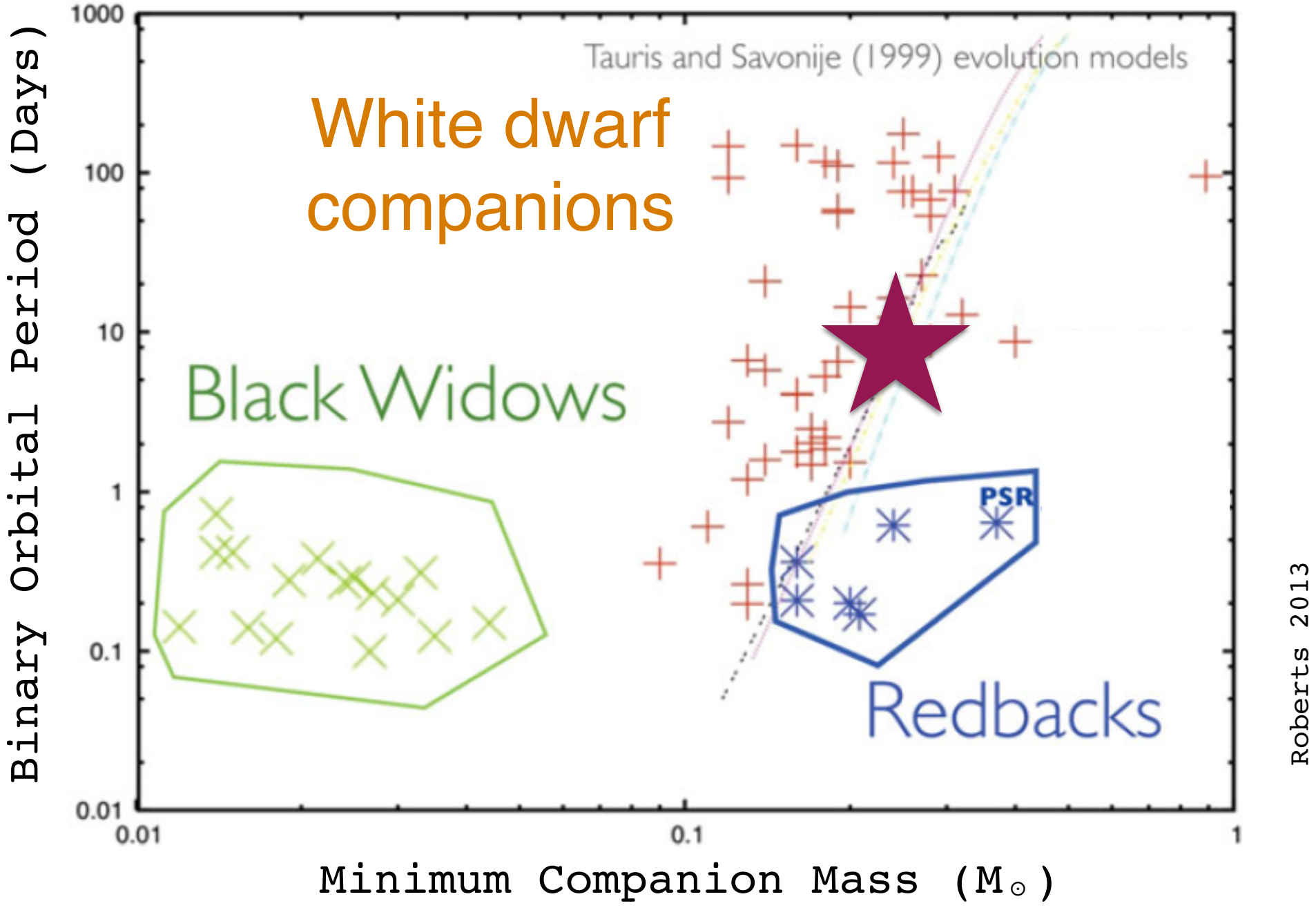



Long Period (5.4 days)➜ **Red giant** secondary!



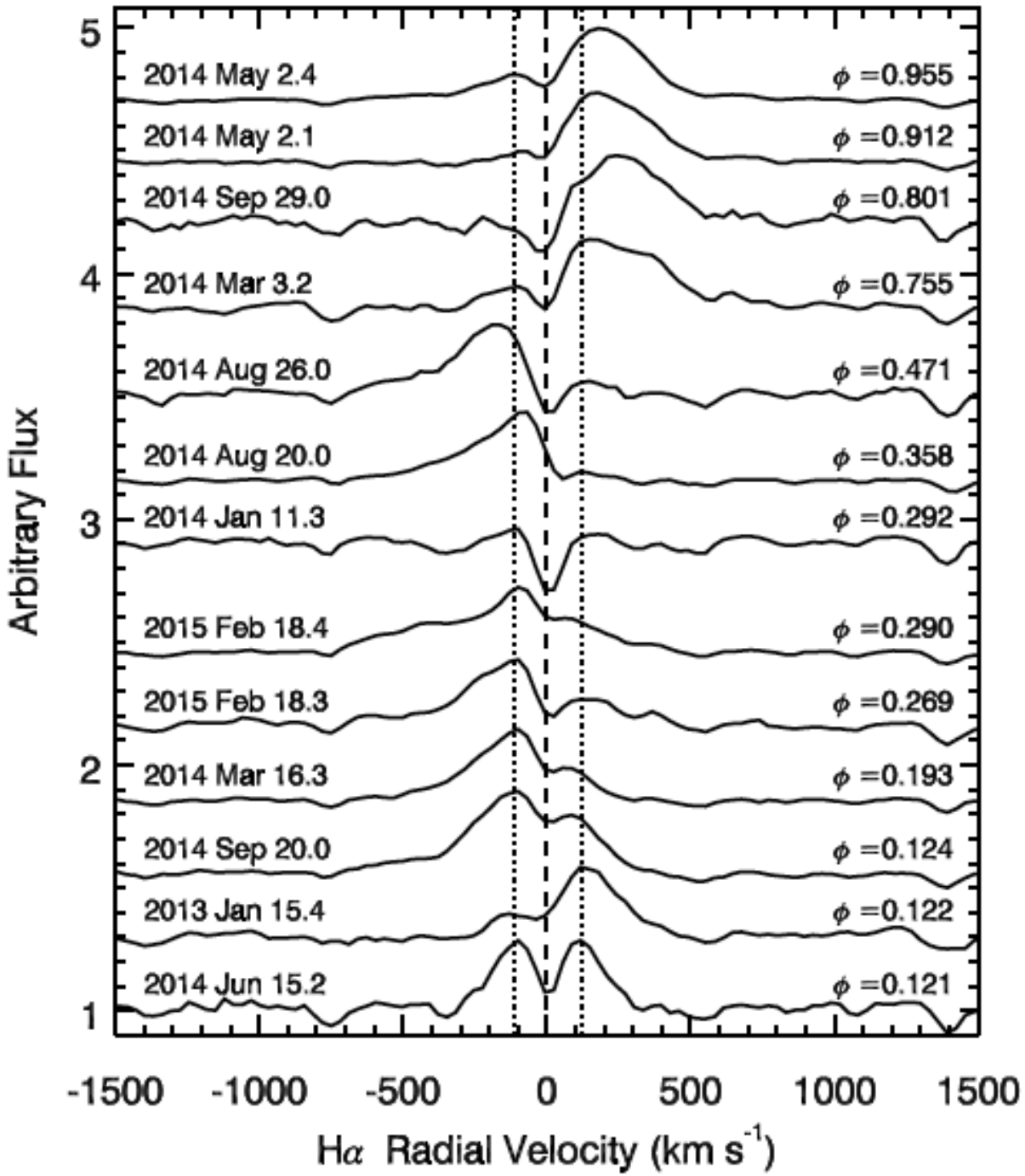

Strader et al 2015

# J1417 is a progenitor system of "normal" MSPs




Roberts 2013

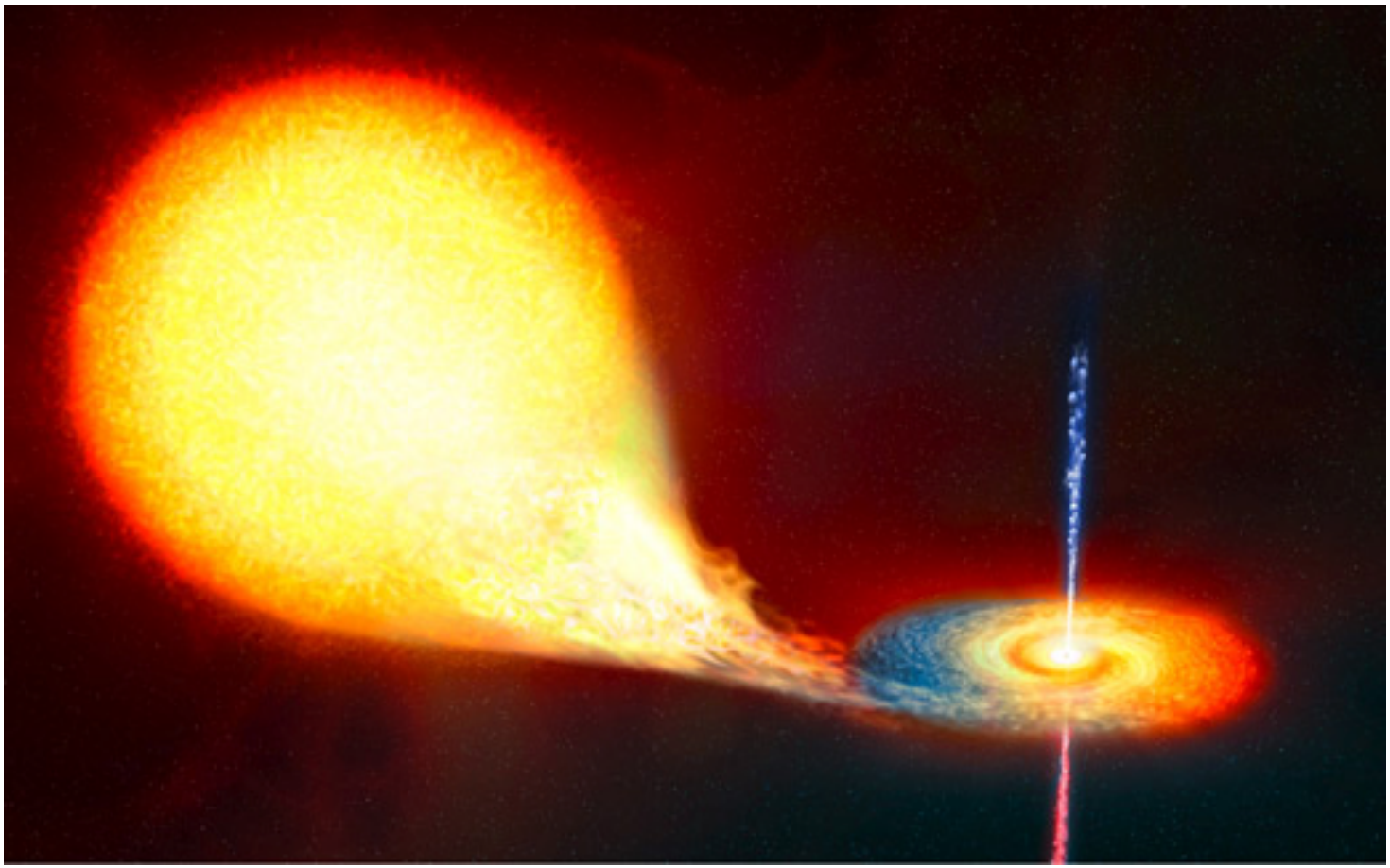
# J1417 Hα



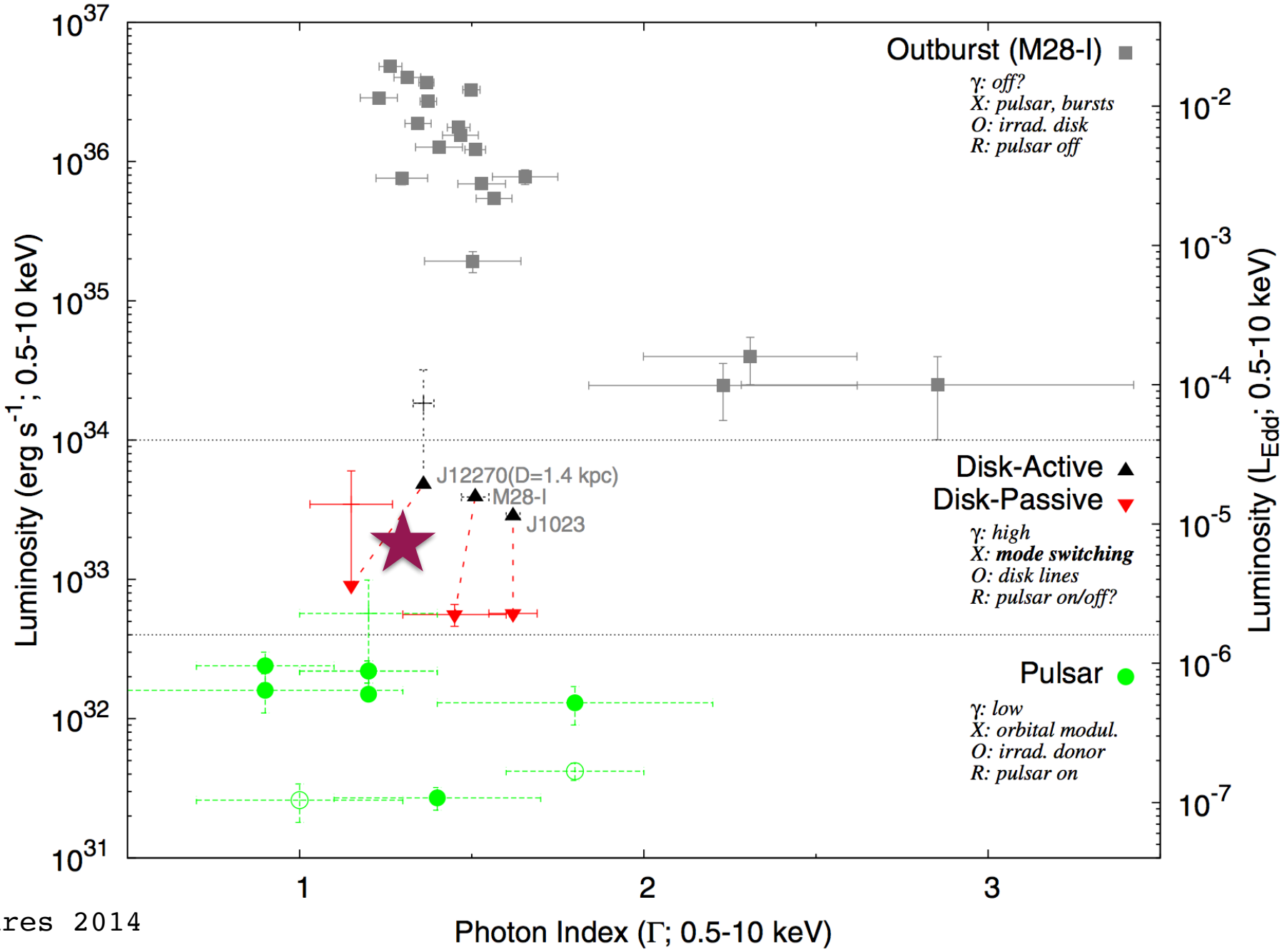

Emission line profile is double-peaked at most epochs, implying an accretion disk

Strader et al 2015

# J1417: a transitional MSP in the accretion-powered (LMXB-like) state?



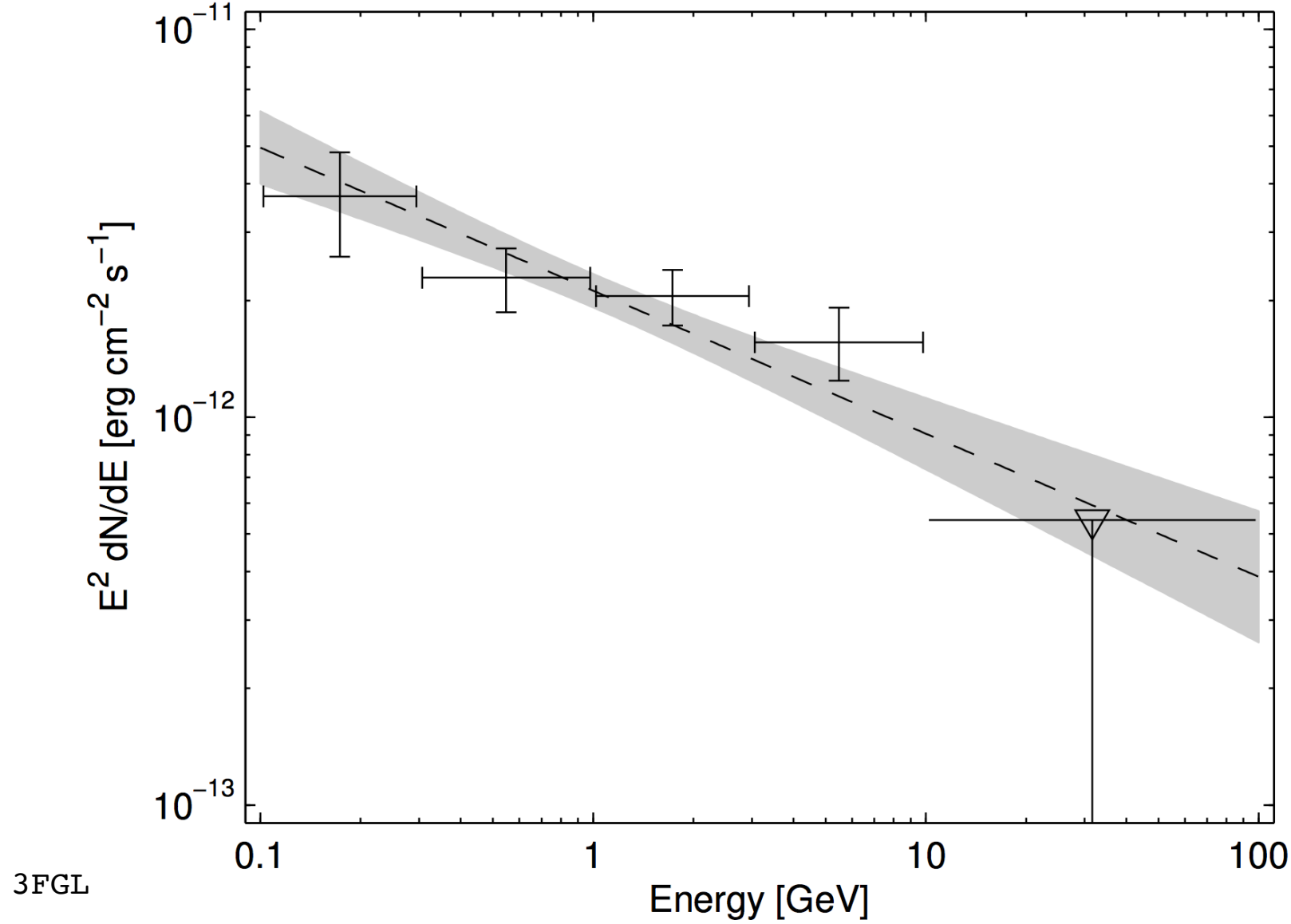
ESA




Linares 2014

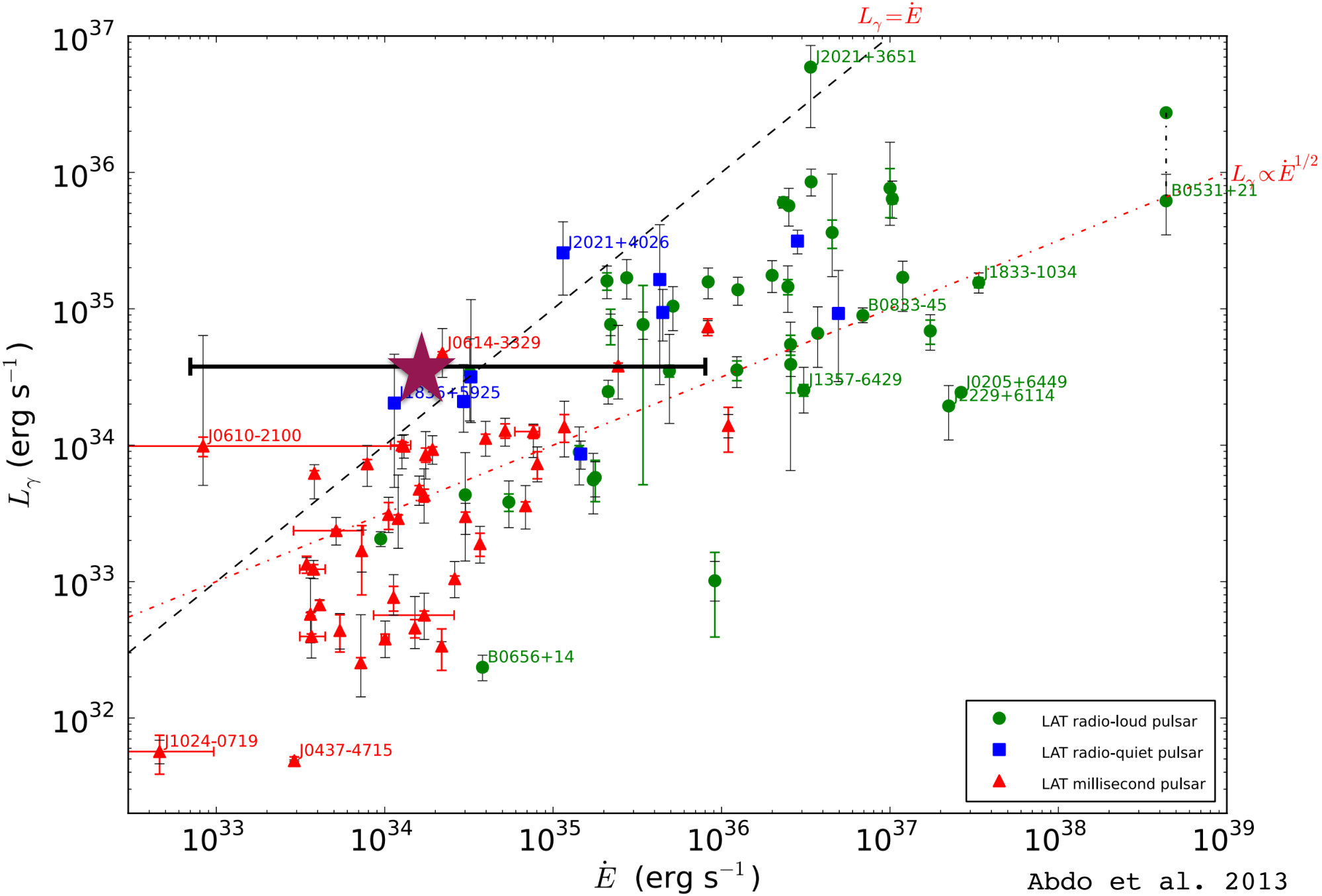
X-ray luminosity too high for pulsar state: more energetic shock due to wind(?)

# J1417 *Fermi*/LAT Emission




spectrum is power-law with index ~ 2.4, curvature not required

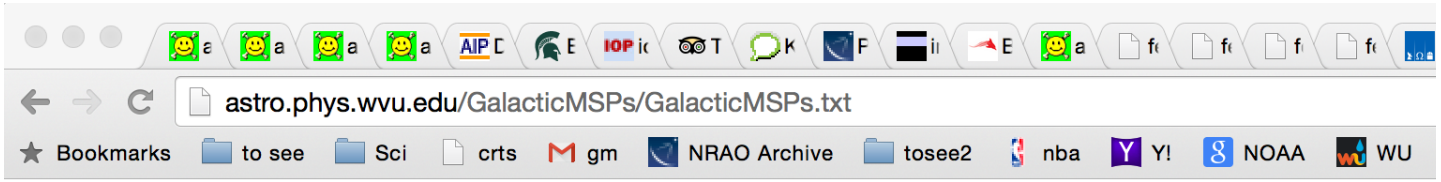
# J1417: γ-ray luminosity higher than nearly all MSPs




Abdo et al. 2013

# J1417: A Huntsman under control?

# J1417 detected as a millisecond pulsar!




```
#================================================================================
#GalacticMSPs.txt lists all published and unpublished millisecond pulsars
#not associated with a globular cluster. A millisecond pulsar is defined as
#P < 30 ms. Send any updates/corrections to duncan.lorimer@gmail.com
#
#From left to right, the columns list the pulsar name, spin period (P in ms),
#dispersion measure (DM in pc/cc), Galactic longitude (l in deg), Galactic
#latitude (b in deg), orbital period (Pb in days), projected semi major axis
#(x in light s) and some discovery notes (year, telescope and survey). Those
#pulsars with no orbiting companions are currently known are listed as N/A.
#Parameters not yet measured (or not known) are denoted by a "*".

  B1257+12  6.22  10.2 311.3  75.4  pulsar planets 1990 AO-430
J1301+0833  1.84  13.2 310.8  71.3   0.272   0.078 2010 GBT-Fermi
J1308-23    2.83  22.4 308    39       *       * 2015 GBT-GBNCC
J1302-3258  3.77  26.2 305.6  29.8   0.784   0.928 2009 GBT-Fermi
J1311-3430  2.56  37.9 307.7  28.2   0.065   0.011 2012 GBT-Fermi
J1312+0051  4.23  15.3 314.8  63.2  38.504  14.750 2010 GBT-Fermi
J1327-0755  2.68  27.9 318.4  54.8   8.439   6.645 2009 GBT-Drift
J1337-6423  9.42 260.3 307.9  -2.0   4.785  13.086 2012 PKS-HTRU
J1400-14    3.08   4.9 327.0  45.3   9.5     8.1   2011 GBT-Drift
J1405-4656  7.60  13.9 315.8  14.1   8.956   6.56  2013 PKS-HTRU
J1417-44    2.66  55   318.9  16.5     *       *   2015 PKS-Fermi
J1421-44    6.38  55   319.4  15.7  binary   TBD  2015 PKS-SUPERB
J1431-4715  2.01  59.4 319.9  12.3   0.449   0.550 2013 PKS-HTRU
J1431-5740  4.11 131.5 315.9   2.7   2.726   2.270 2013 PKS-HTRU
J1435-6100  9.35 113.7 315.2  -0.6   1.355   6.184 2001 PKS-PMPS
J1439-5501 28.64  14.6 318.1   4.6   2.118   9.833 2004 PKS-PMPS
J1446-4701  2.19  55.8 322.5  11.4   0.278   0.064 2012 PKS-HTRU
J1453+1902  5.79  14.1  23.4  60.8    N/A     N/A  2007 AO-430
J1455-3330  7.99  13.6 330.7  22.6  76.175  32.362 1995 PKS-SSS
```

(Camilo et al.)

Given the evidence for a ~constant accretion disk over the last ~2 yr, some (uncomfortable) options:

— J1417 is a transitional MSP with short (days?) transition timescales

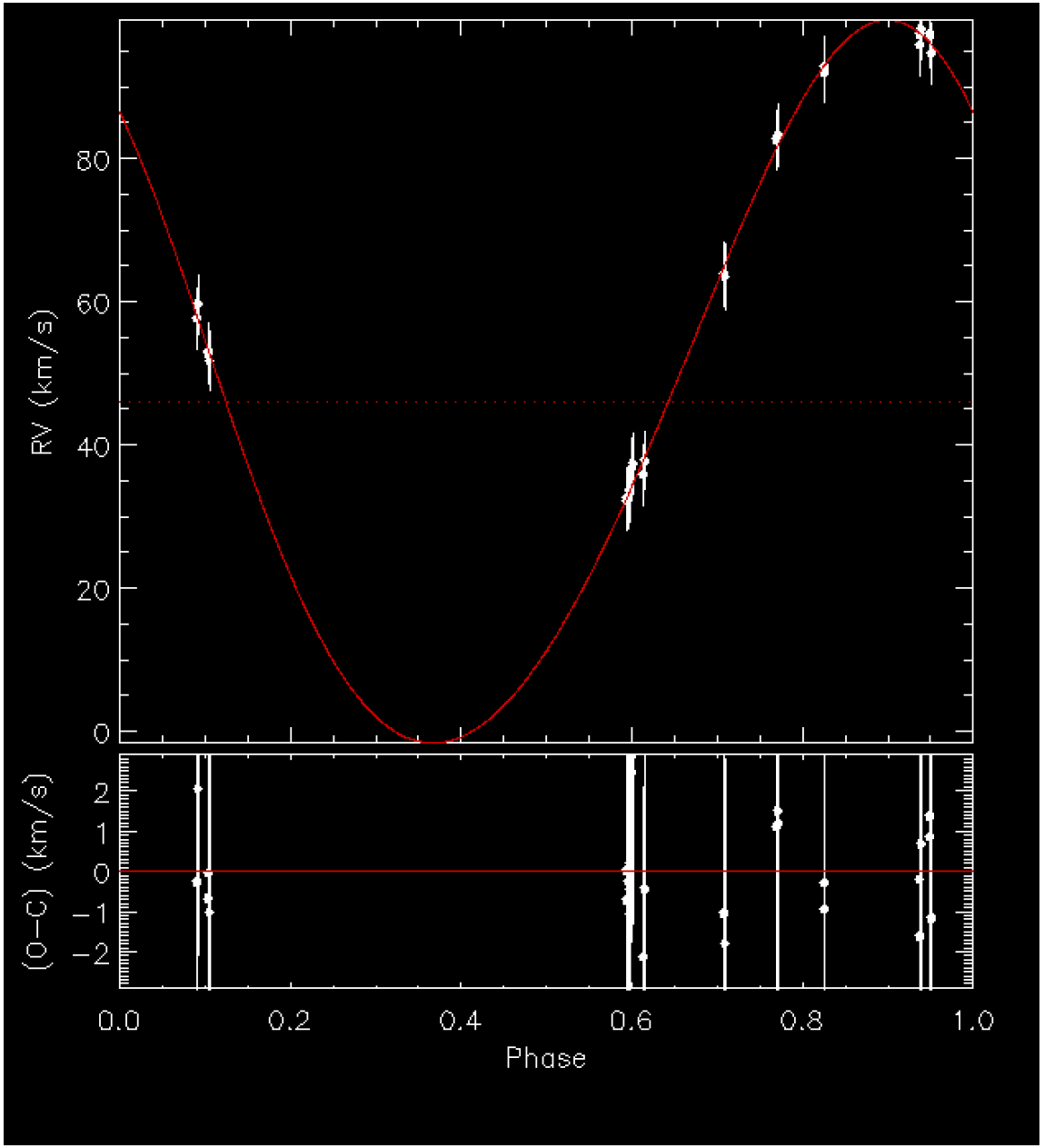
— Despite the presence of a disk in J1417, no accretion actually occurs

— It is possible to have the simultaneous occurrence of accretion and a radio pulsar

# Progress on J1417:

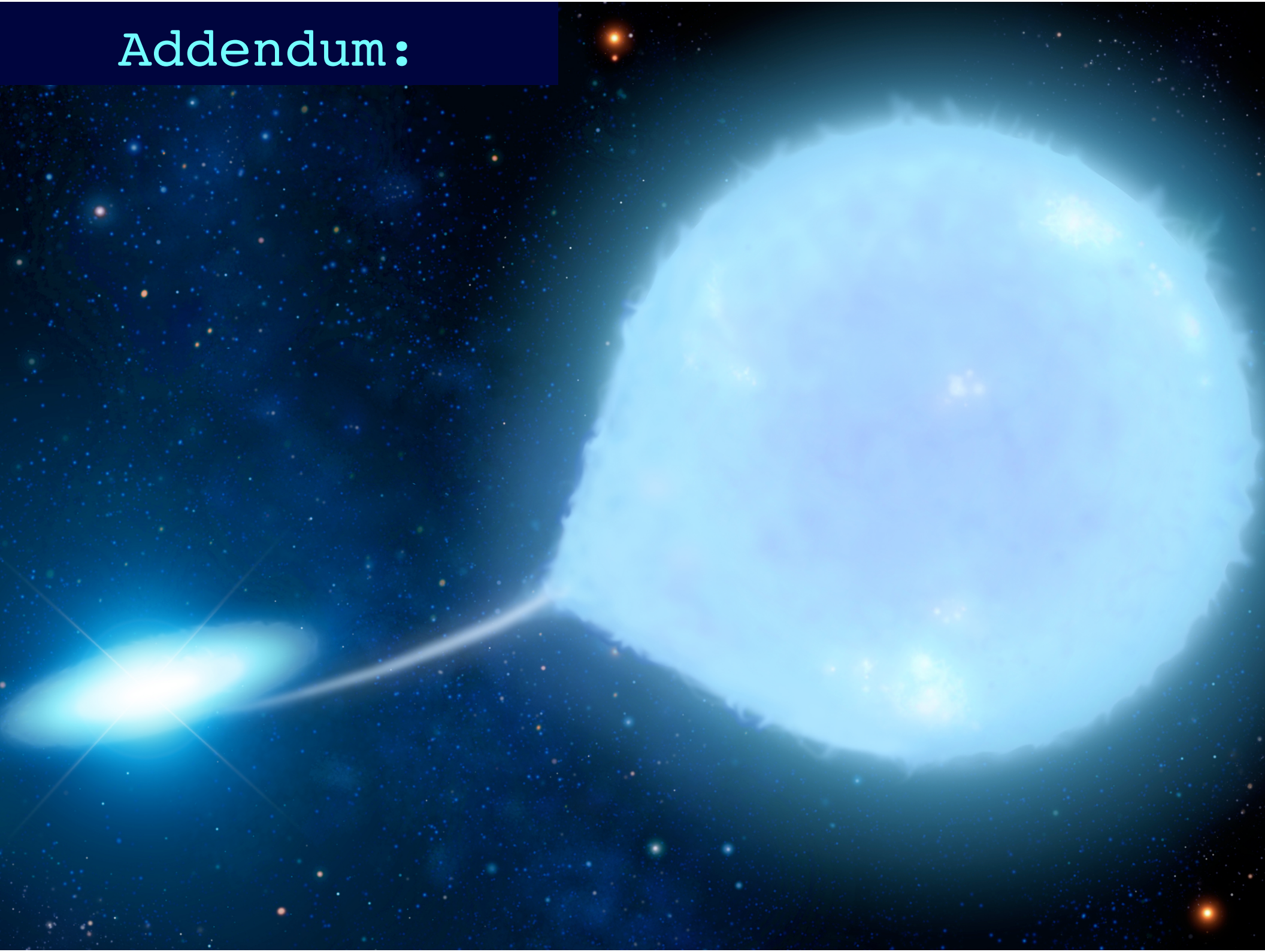
- Look for X-ray mode switching in *Chandra* data (approved)
- Radio observations to search for (or rule out) a bright jet
- Ongoing optical observations to monitor state of disk
- Ongoing Fermi observations to look for variability
- Pulsar timing observations will yield better constraints on mass of neutron star

# J1417 is not alone



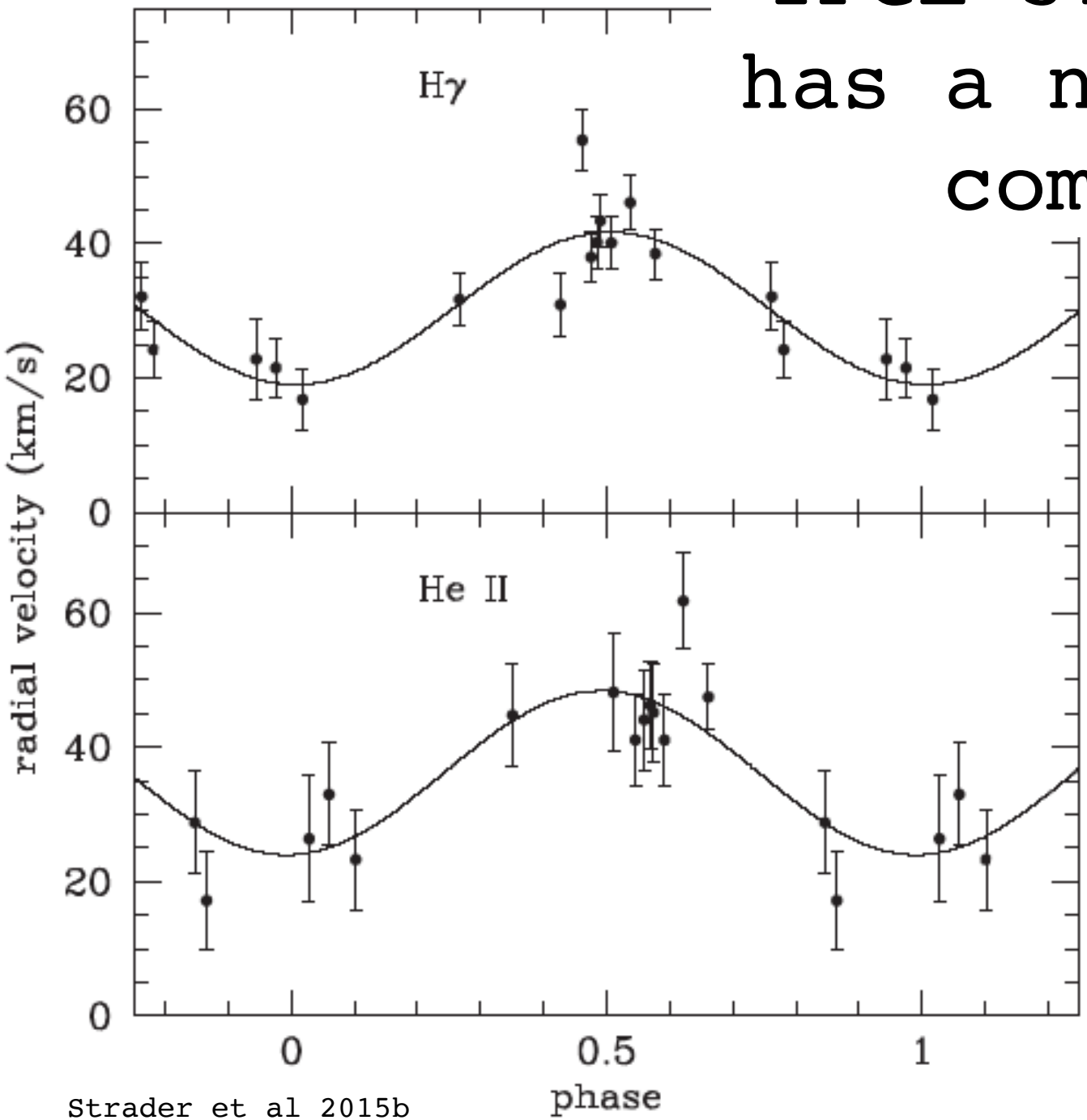

We have at least one more very similar object: *Fermi* source with neutron star primary and giant secondary

# Addendum:



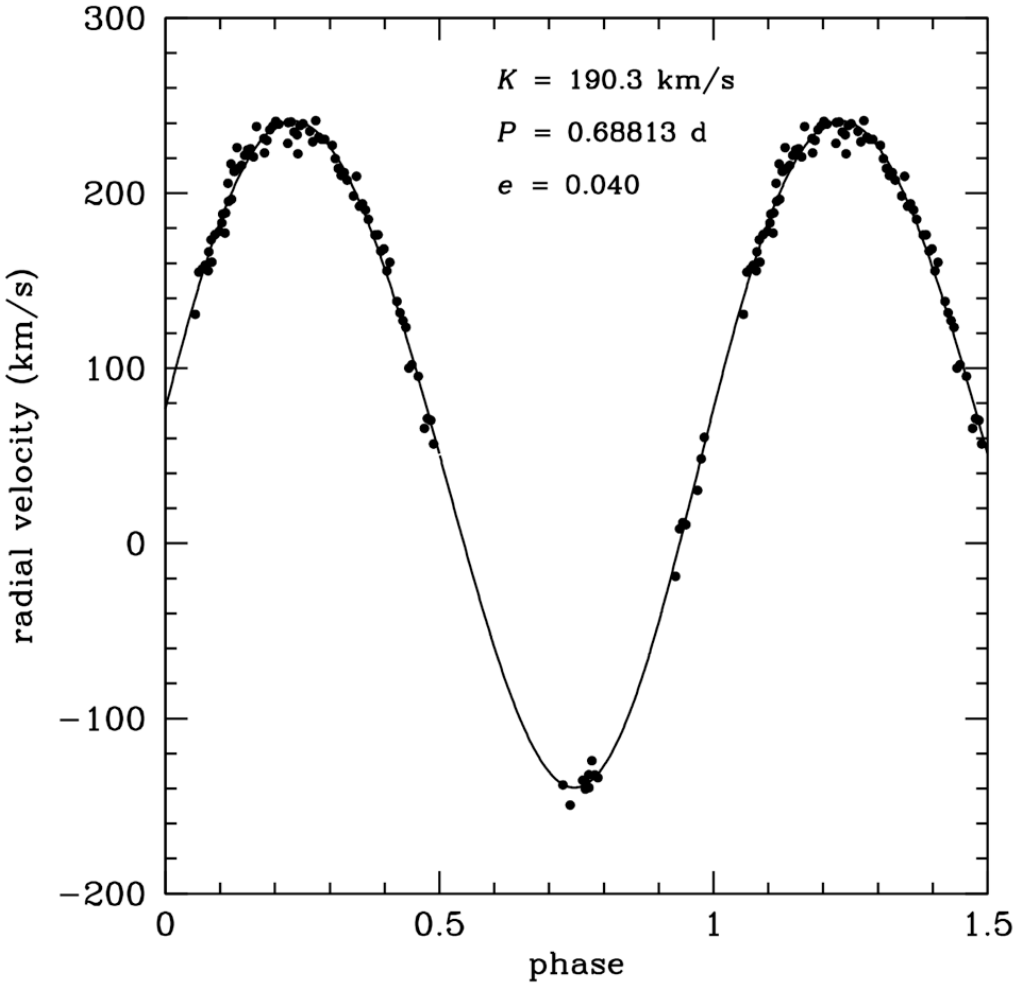
# Addendum:

## 1FGL J1018.6-5856 has a neutron star companion.




Strader et al 2015b

# 1FGL J0523.5-2529




$K_2$ = 190 km/s

P ~ 0.688 days

e ~ 0.04

redback with eccentricity: very unusual

# Parameters for J0523

$$M_1 = 2.08^{+0.36}_{-0.28} M_\odot$$

$$M_2 = 1.28^{+0.31}_{-0.25} M_\odot$$

Again, a massive neutron star
(with a large uncertainty—could improve a little)

The more unusual conclusion is that the secondary is so massive—much more so than any other redback

# Parameters for J0523

$$M_1 = 2.08^{+0.36}_{-0.28} M_\odot$$

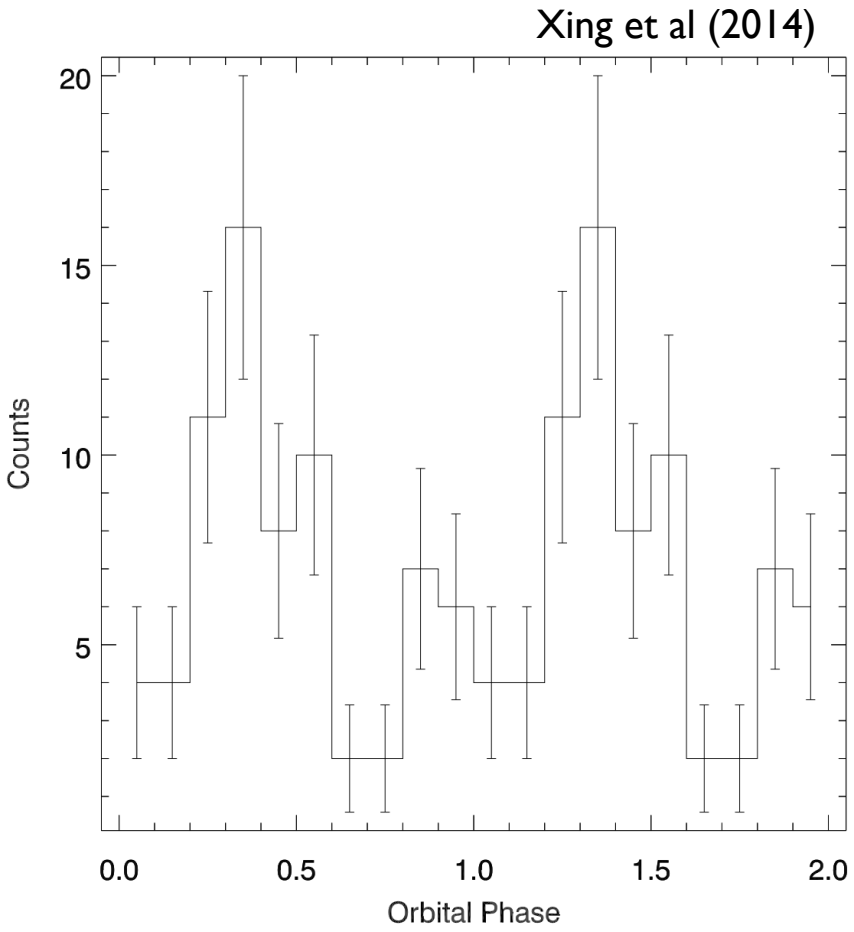
$$M_2 = 1.28^{+0.31}_{-0.25} M_\odot$$

Again, a massive neutron star
(with a large uncertainty—could improve a little)

The more unusual conclusion is that the secondary is so massive—much more so than any other redback

Detecting primary as a pulsar would help a lot!
We have obtained 6 hr of GBT time to search for a pulsar (search ongoing)

# High-energy emission




Evidence for orbital variability in gamma-rays above 2 GeV: suggests some gamma-ray emission from a shock